Simulations of magnetoconvection and Solar-B

MPS

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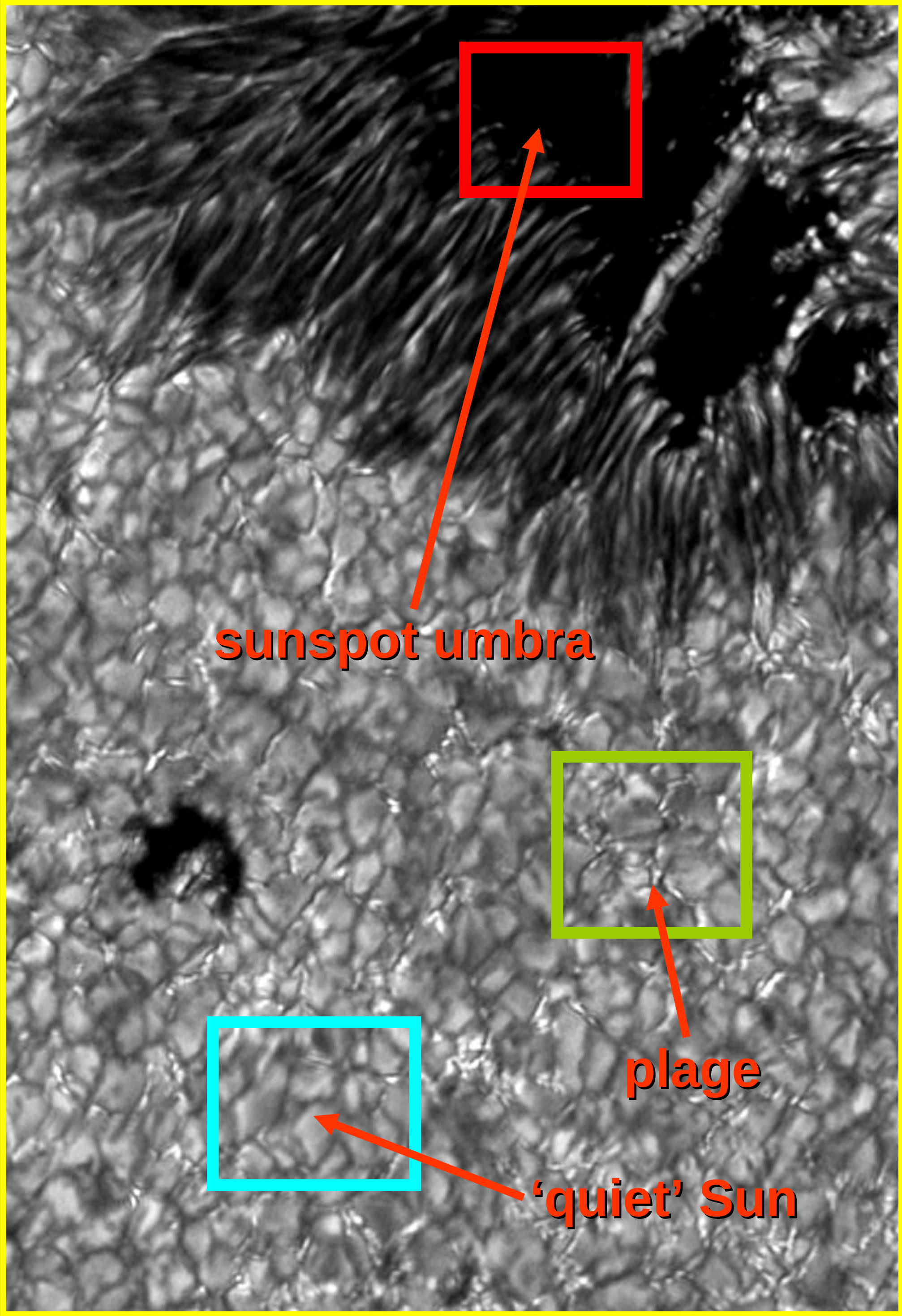
Regimes of solar magneto-convection

quiet Sun | plage | sunspot umbra

→ average B

- horizontal scale of convection decreases
- convective energy transport decreases



G-band image: VTT, Tenerife

MPS/UofC Radiation MHD (*MURaM*) Code

Developed by the MPS MHD group (A. Vögler, R. Cameron, S. Shelyag, M. Schüssler)
in cooperation with F. Cattaneo, Th. Emonet, T. Linde (Univ. of Chicago)
http://www.mps.mpg.de/projects/solar-mhd/muram_site

- 3D compressible MHD
- cartesian fixed grid
- radiative transfer: short characteristics non-grey (opacity binning), LTE
- partial ionisation (11 species)
- 4th order centered spatial difference scheme
- explicit time stepping: 4th order Runge-Kutta
- MPI parallelized (domain decomposition)
- and: extensive diagnostic tools to compare with observations (e.g. continuum, spectral line & polarization diagnostics)

Solar-B

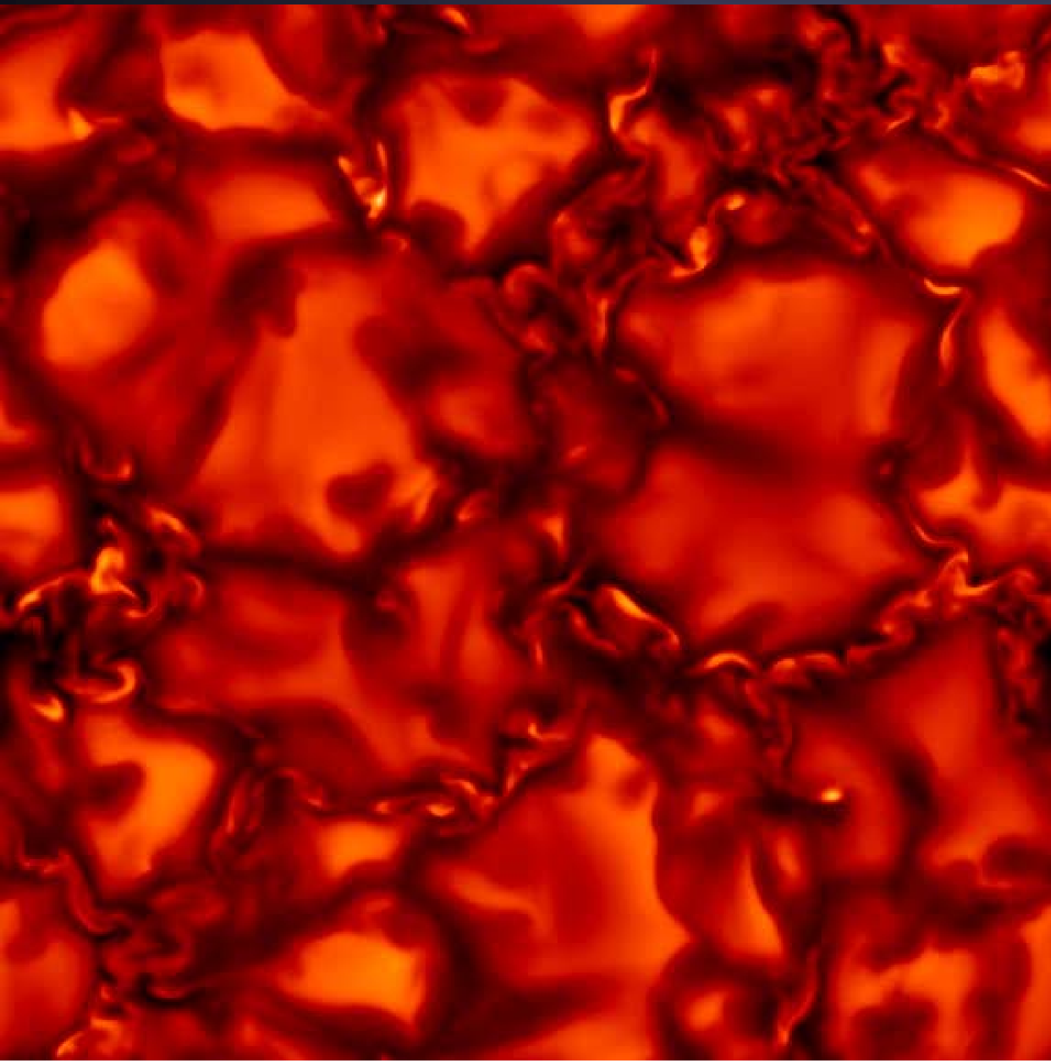
Applications and Results of MURaM

- Structure and dynamics of photospheric flux concentrations (Vögler et al., 2003, 2005; Vögler & Schüssler 2003; Vögler 2003, 2004)
- Fractal dimension of magnetic patterns (Janssen et al. 2003)
- Effect of non-grey radiative transfer (Vögler et al. 2004)
- Nature of G-band bright points (Schüssler et al. 2003, Shelyag et al. 2004)
- Origin of facular brightening (Keller et al. 2004)
- Solar pores (Cameron et al., 2005)
- Magnetic flux in internetwork fields (Khomenko et al. 2005a, b)
- Nature of umbral dots (Schüssler & Vögler 2006)
- Decay of mixed-polarity fields (Vögler et al, in prep.)
- Flux emergence (Cheung et al., in prep.)
- CLV of facular brightness (Zakharov et al. in prep.)

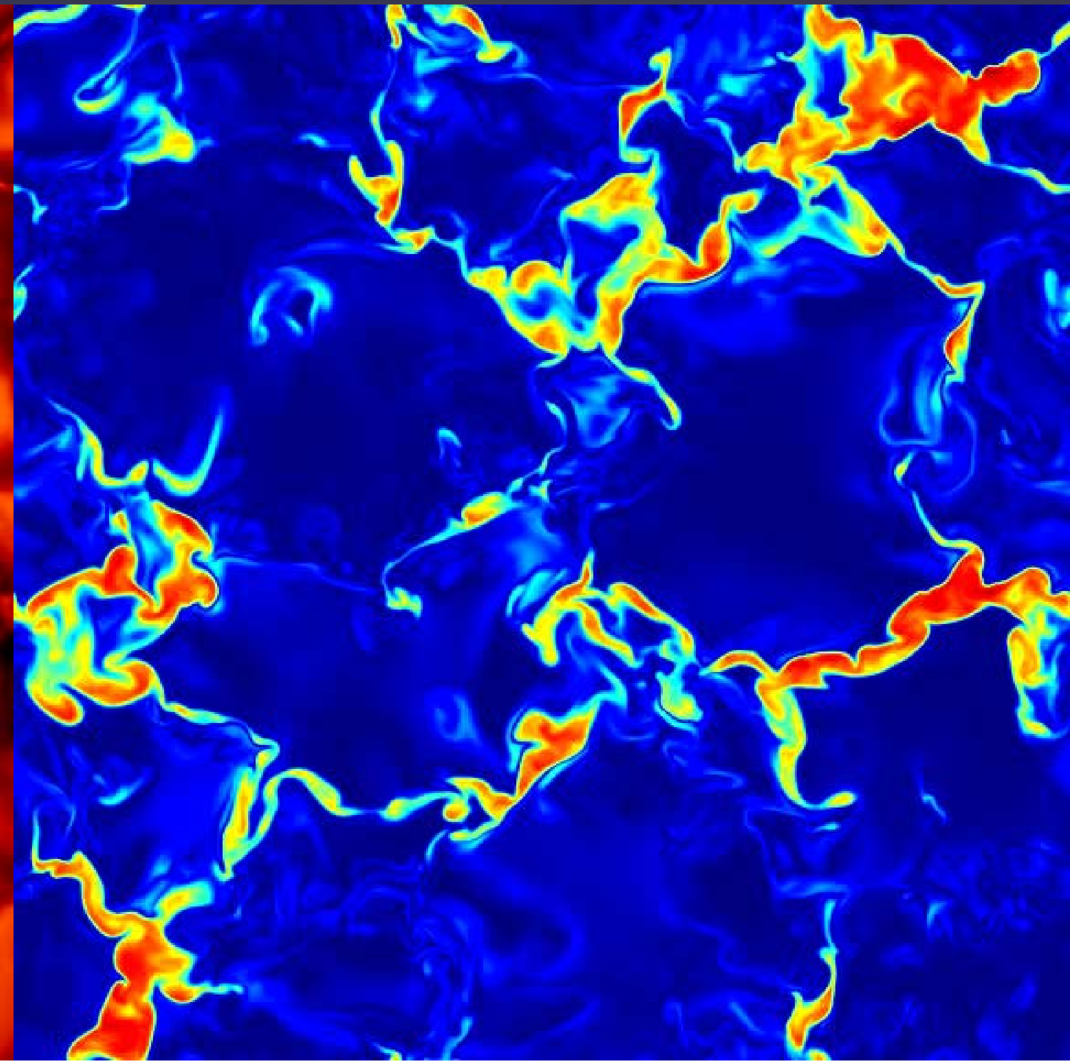
“High Resolution” Simulations

$\langle B_z \rangle$ = 200 G;   Grid: 576 x 576 x 100 (10 km horiz. cell size)

Brightness



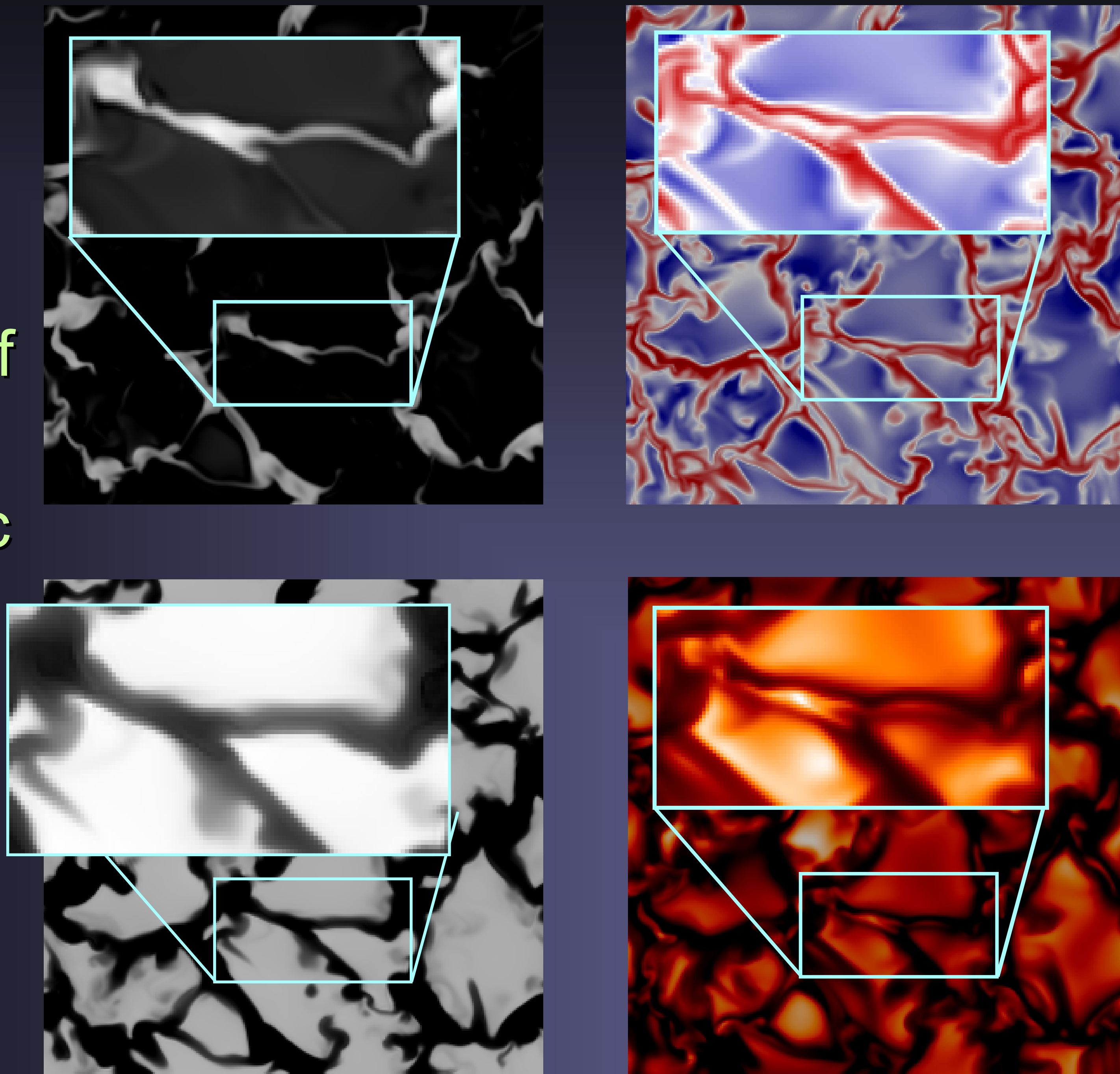
Magnetic field



B_z

v_z

Details of thin magnetic flux sheet



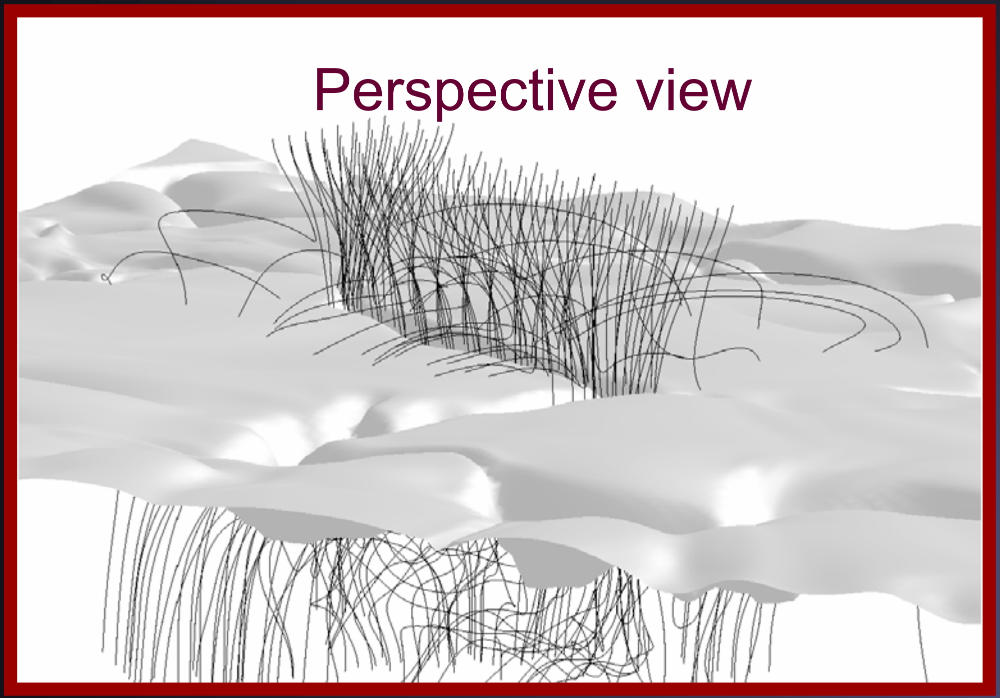
T

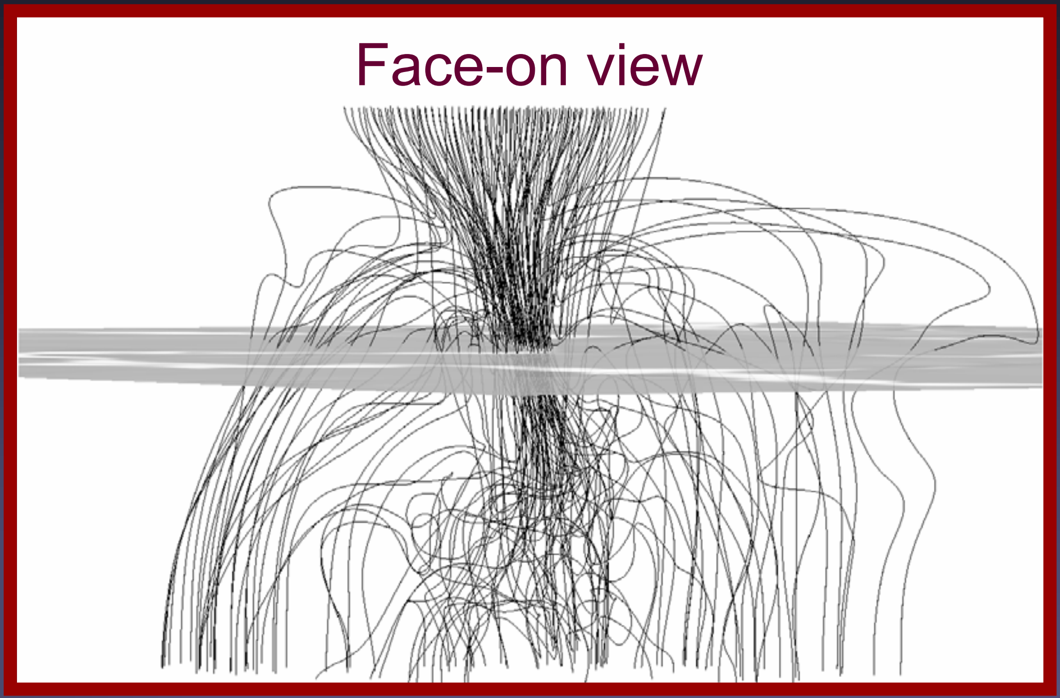
I_C

Horizontal cuts near surface level

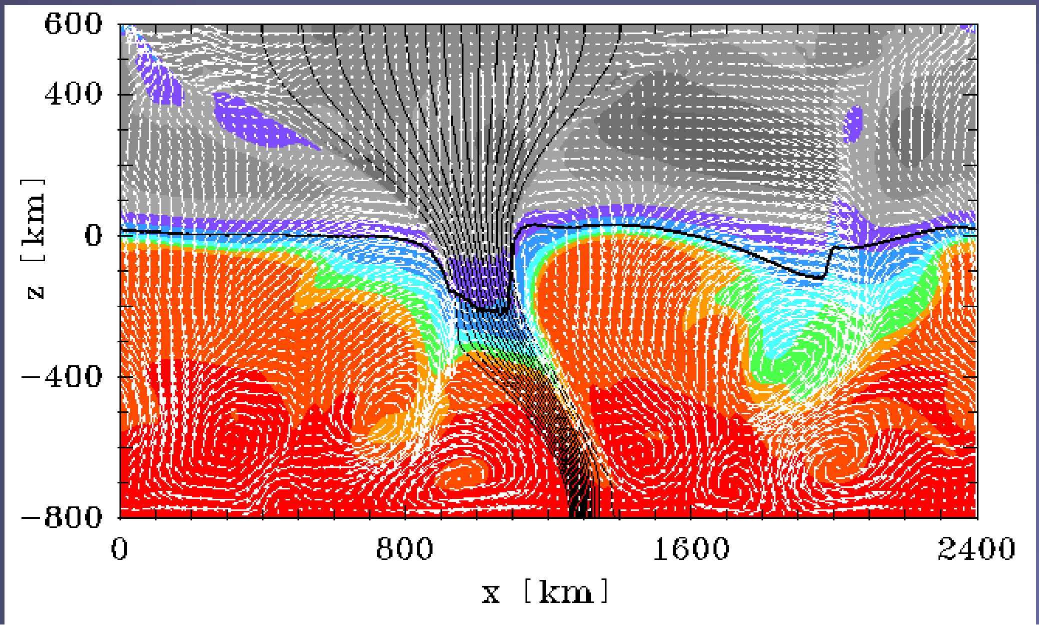
Vögler et al. 2005

3D view of a thin flux sheet





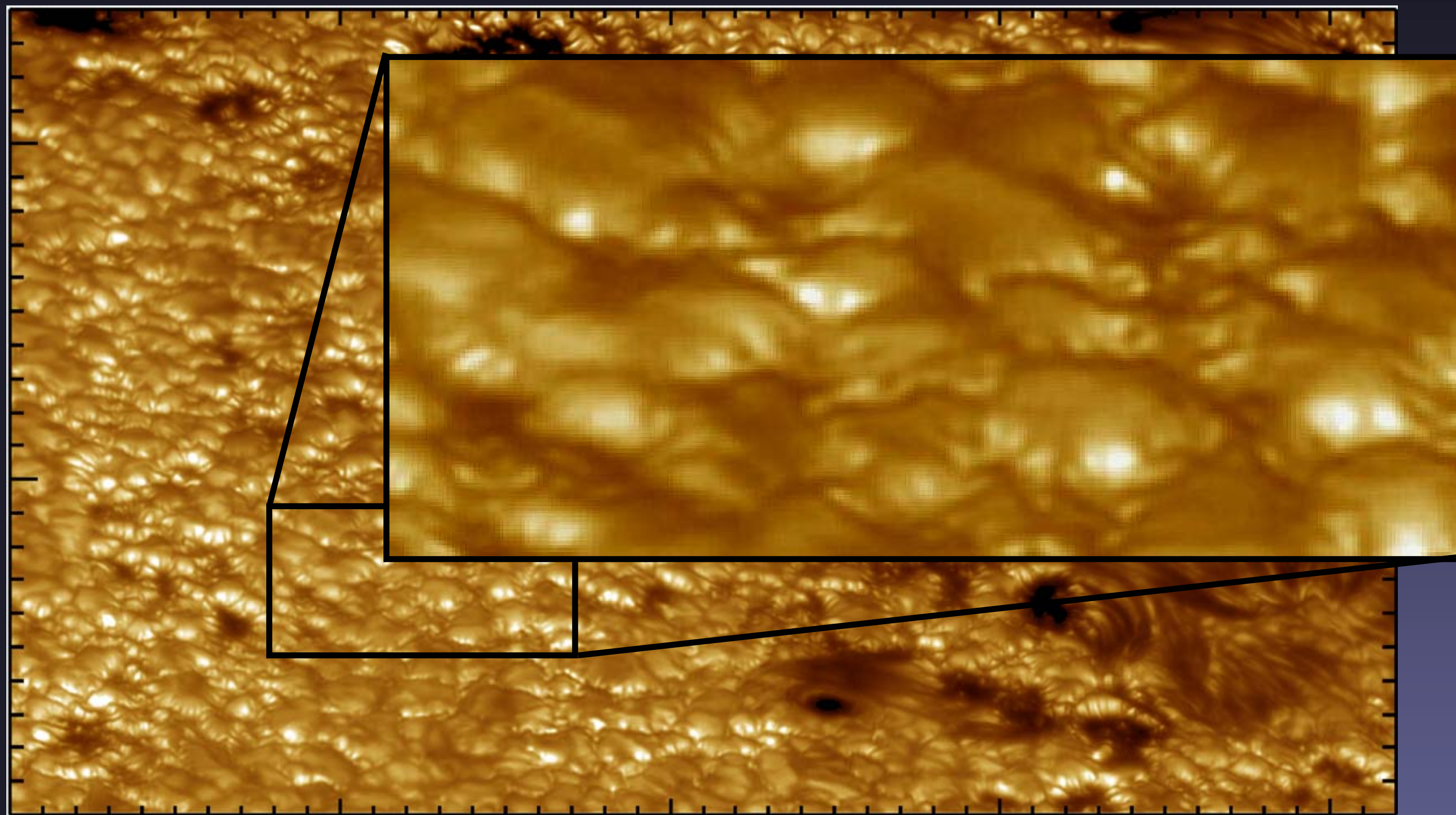
- Quasi 2-dimensional above the surface
- Loss of coherence beneath the surface



Vögler et al. 2005

Steiner et al. 1998

Facular brightening



Limb

Center

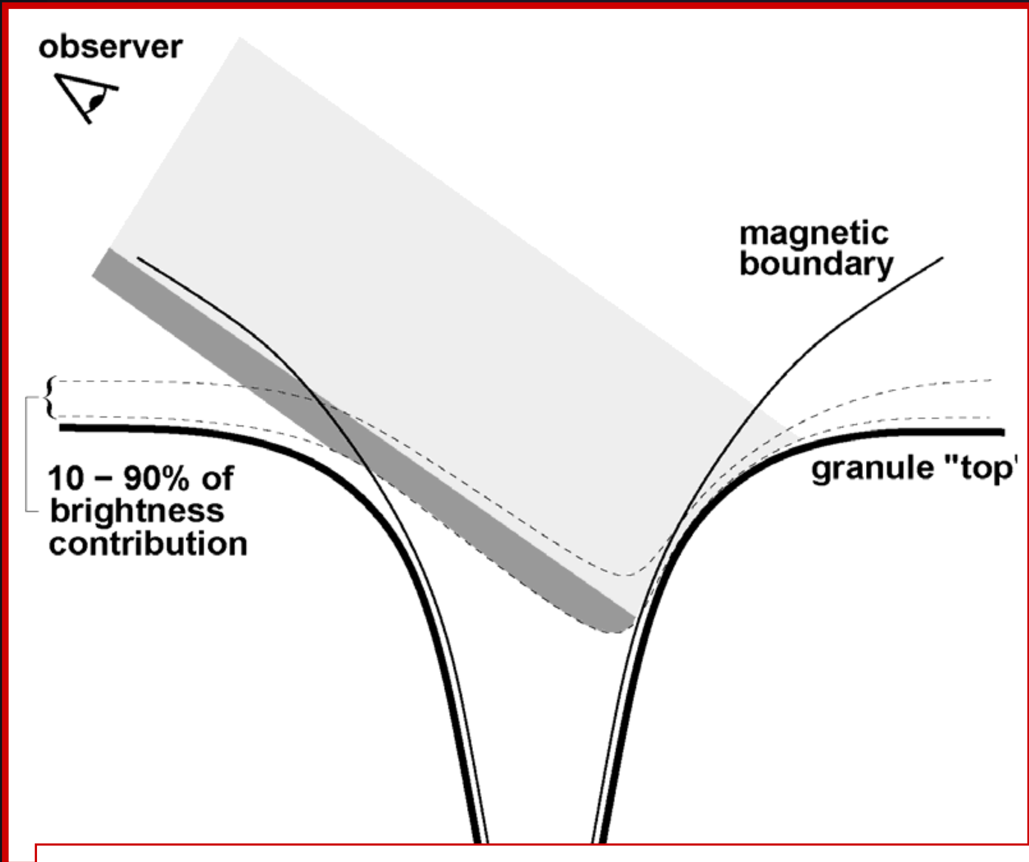
(continuum image: SST, La Palma θ=60° λ=488nm)

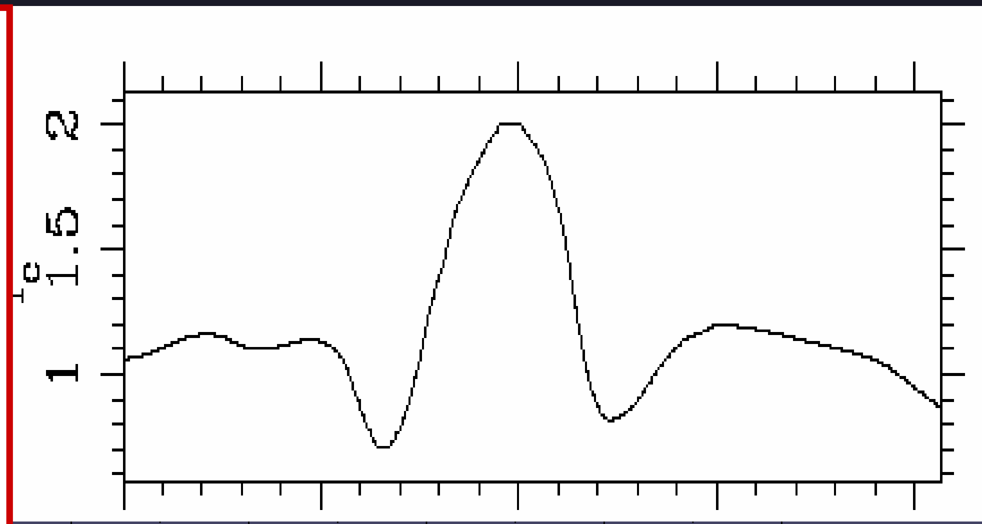
Recent observations reveal:

(Lites et al. 2004)

- 3D appearance of faculae
- extension up to 0.5”
- narrow dark lanes centerward of faculae

Facular brightening

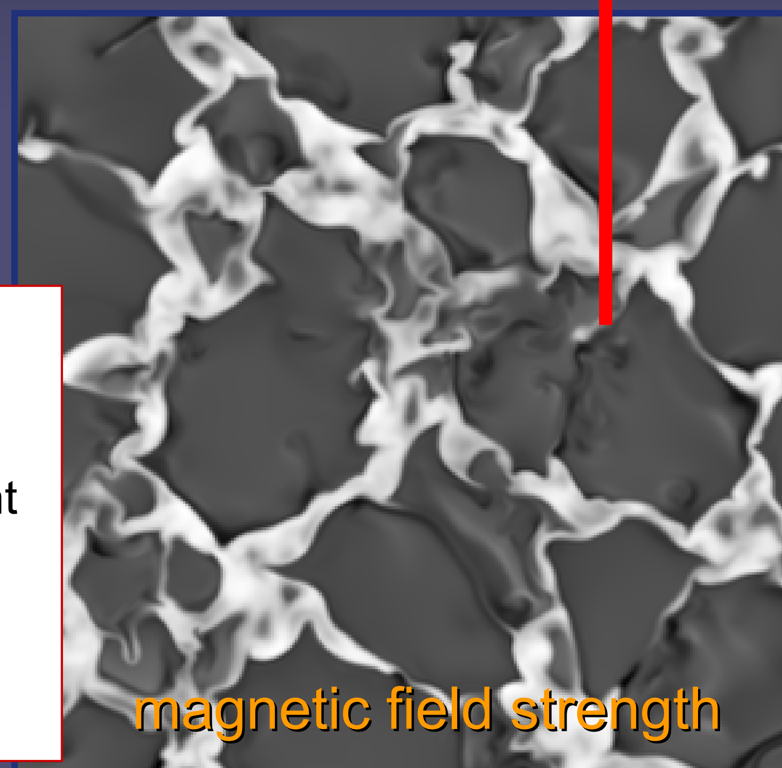




Facula: narrow layer of hot material on side and top of adjacent granule

Dark lane: - cool & tenuous material in adjacent flux concentration

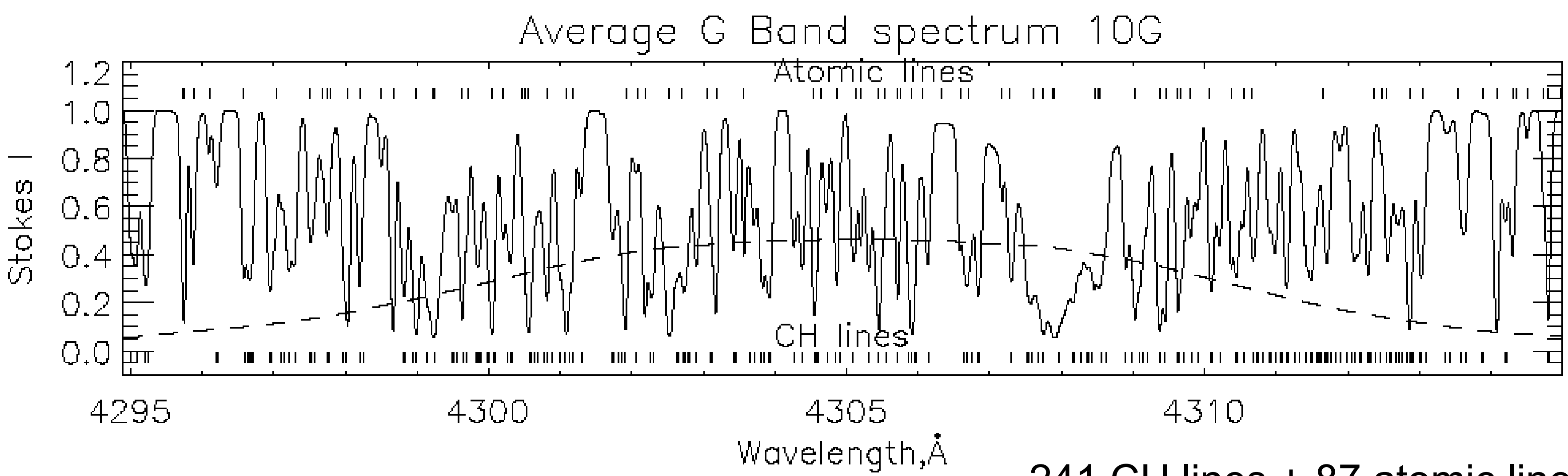
- cool & dense material above neighbouring granule



(Keller et al. 2004)

G-band spectrum synthesis

G-Band (Fraunhofer): spectral range from 4295 to 4315 Å contains many temperature-sensitive molecular lines (CH)



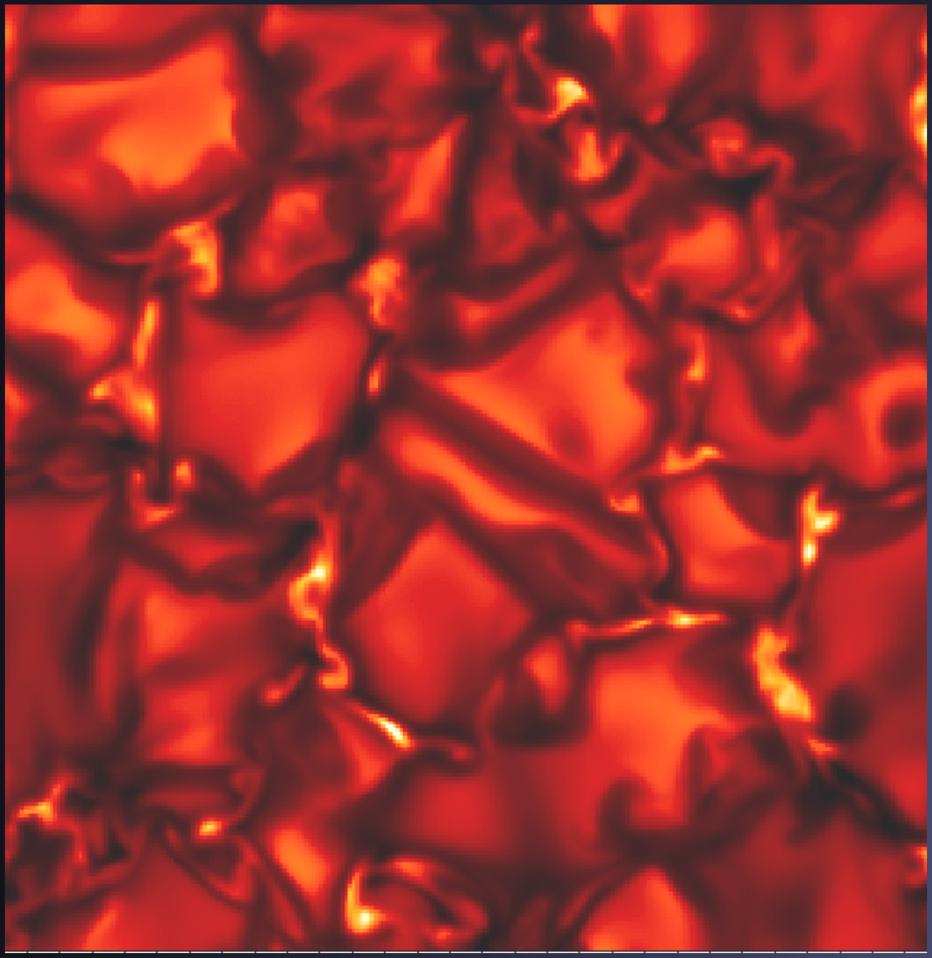
241 CH lines + 87 atomic lines

For comparison with observations, we define as G-band intensity the integral of the spectrum obtained from the simulation data:

$$I_G = \int_{4295\ A}^{4315\ A} I(\lambda)\, d\lambda$$

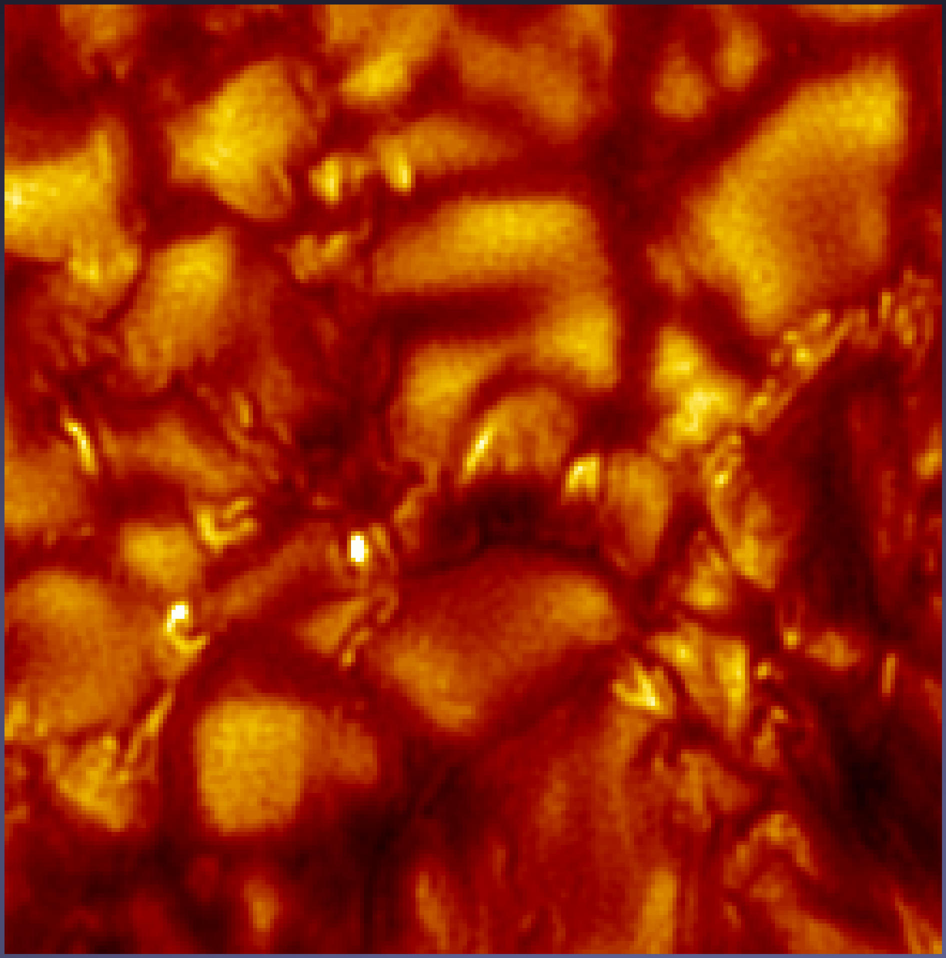
[Shelyag, 2004]

G-band: Simulation vs. Observation



Simulation (20 km resolution)

Schüssler et al. 2003
Shelyag et al. 2003

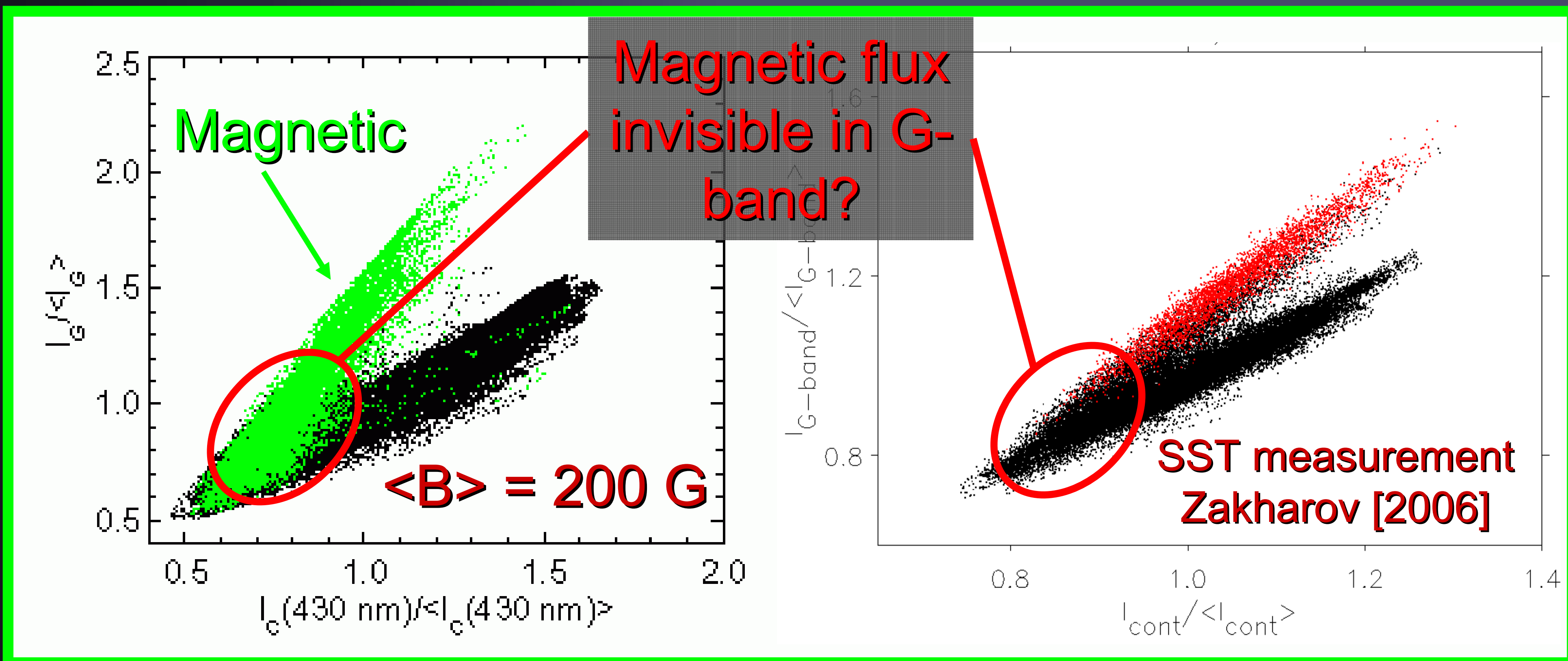


Observation
(~100 km resolution)
(SST, La Palma,
Scharmer et al. 2002)

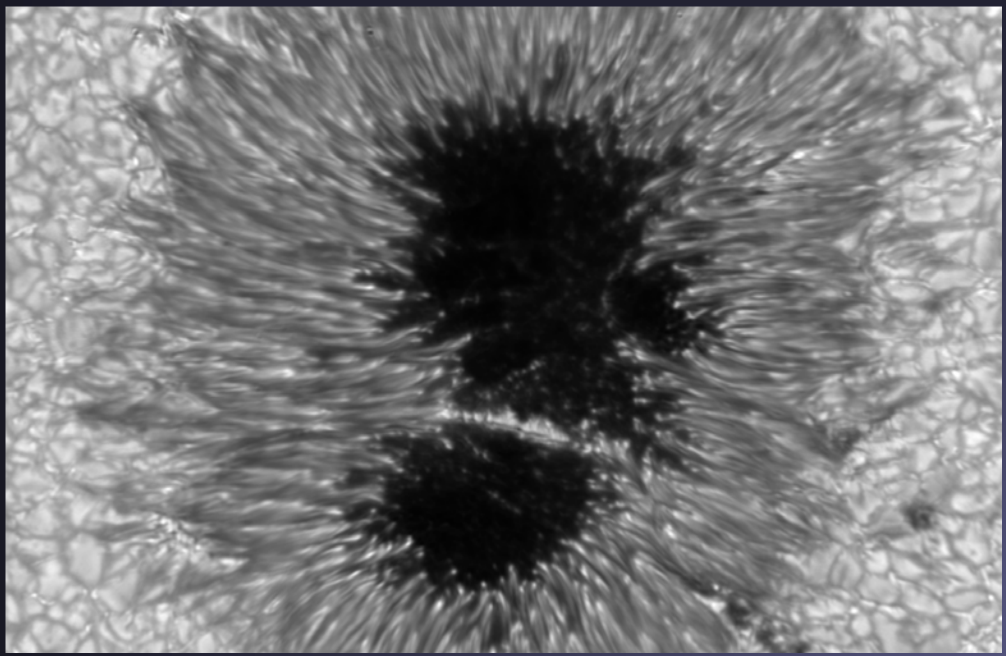
B_z & G-band radiance in simulations and observations

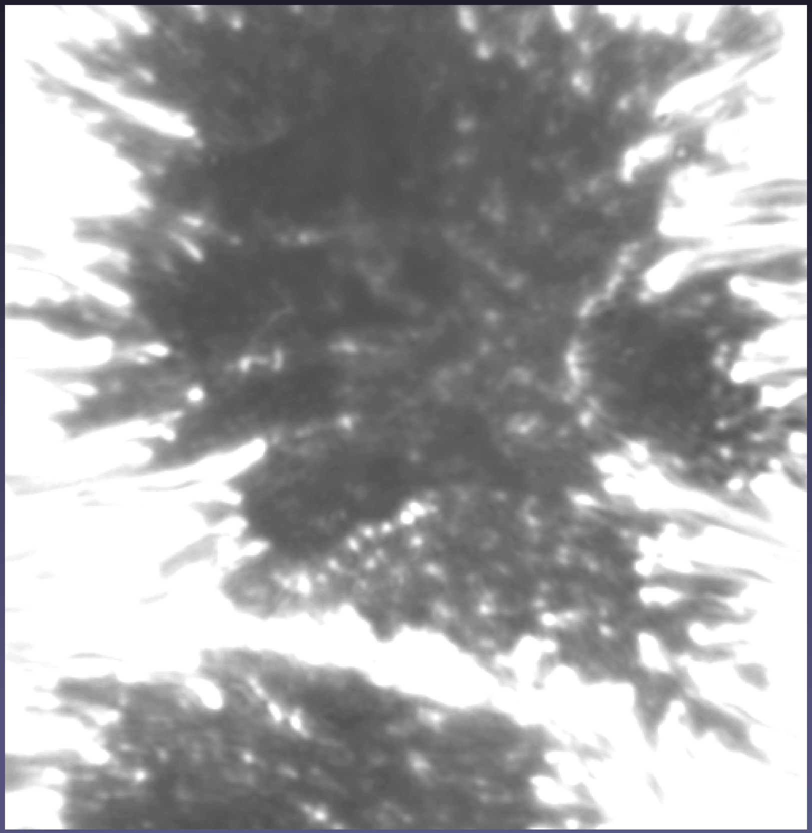
G-band brightness ~ continuum brightness

However, different constants of proportionality for "magnetic" and "non-magnetic" features



Magneto-convection in a sunspot umbra

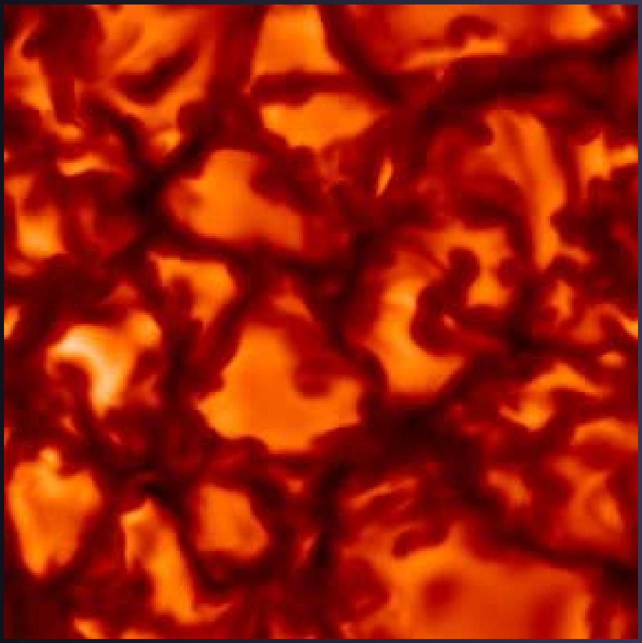




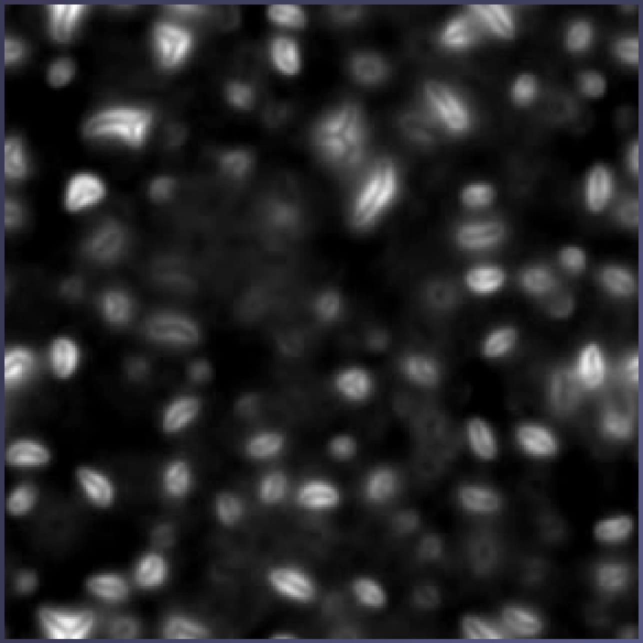
- Suppressed energy transport → dark
- Convective transport required to sustain raditative energy output
- Umbral dots a manifastation of convection ?
  (e.g. overstable oscillations, intrusion of QS plasma)

Time evolution of the brightness pattern

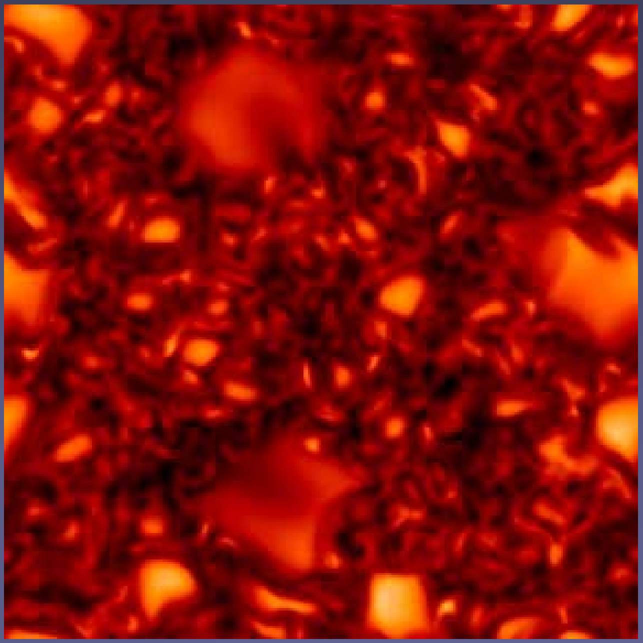
Quiet Sun
<B>= 0



Sunspot umbra
<B>= 2500 G

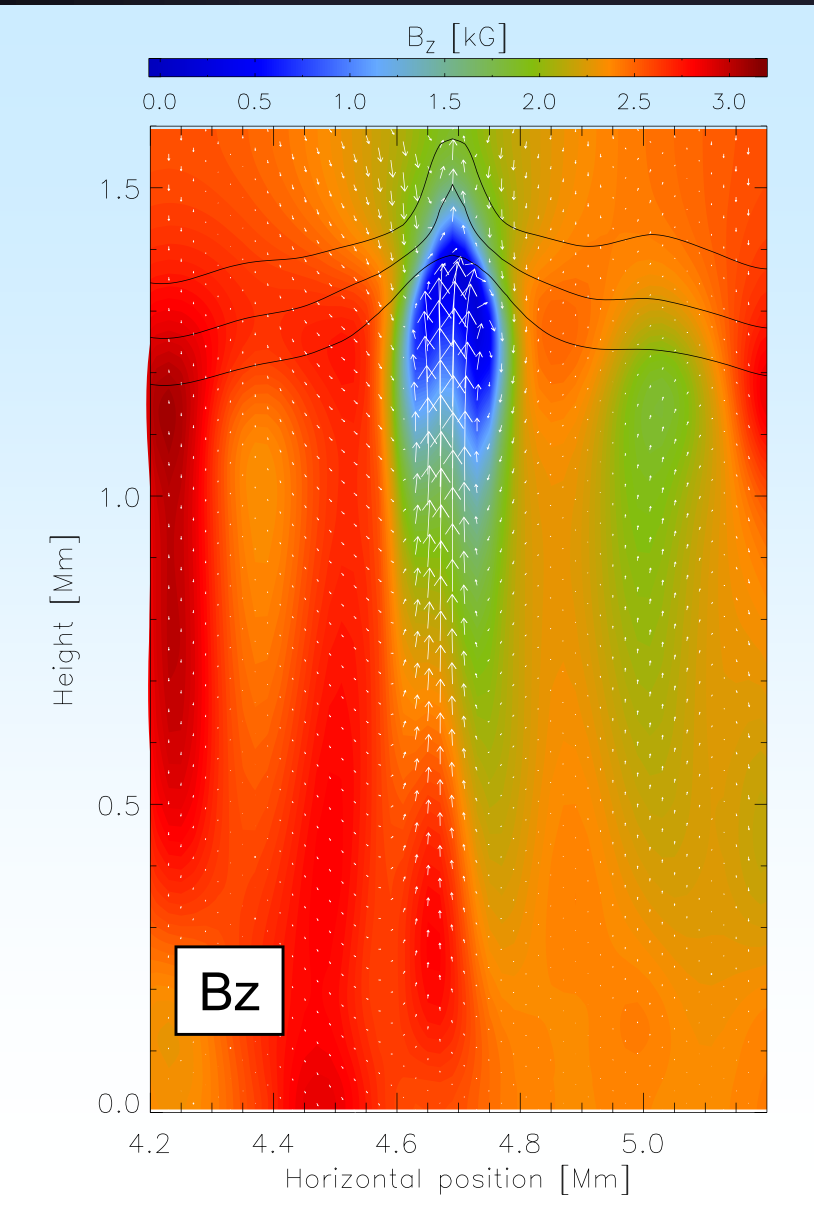


Extreme plage
<B>= 800 G

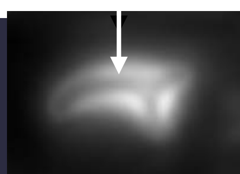


5800 km

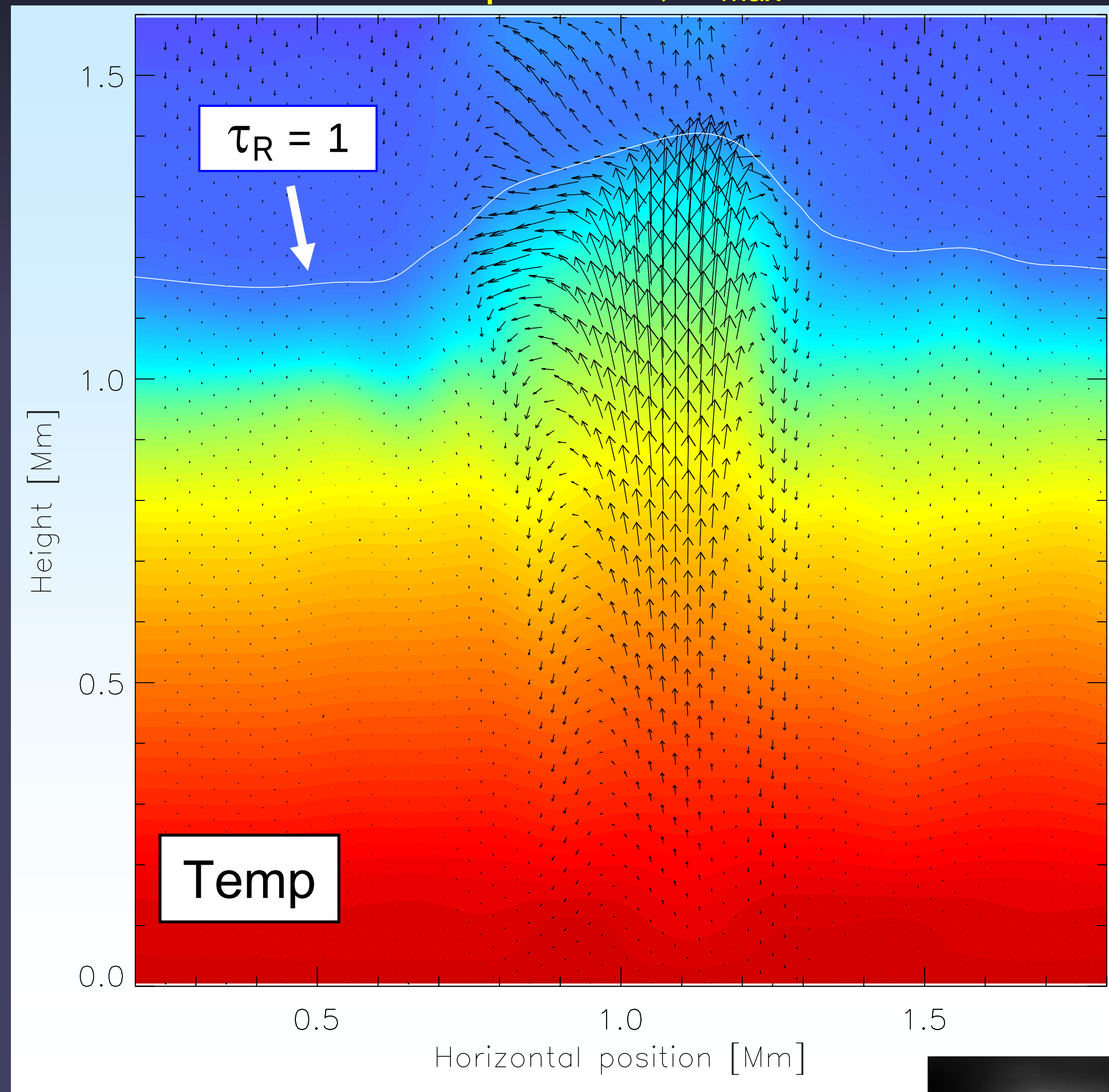
Vertical cuts through an upflow umbral plume



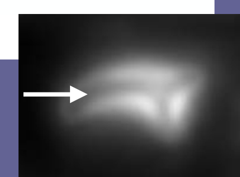
perpendicular
to the dark lane



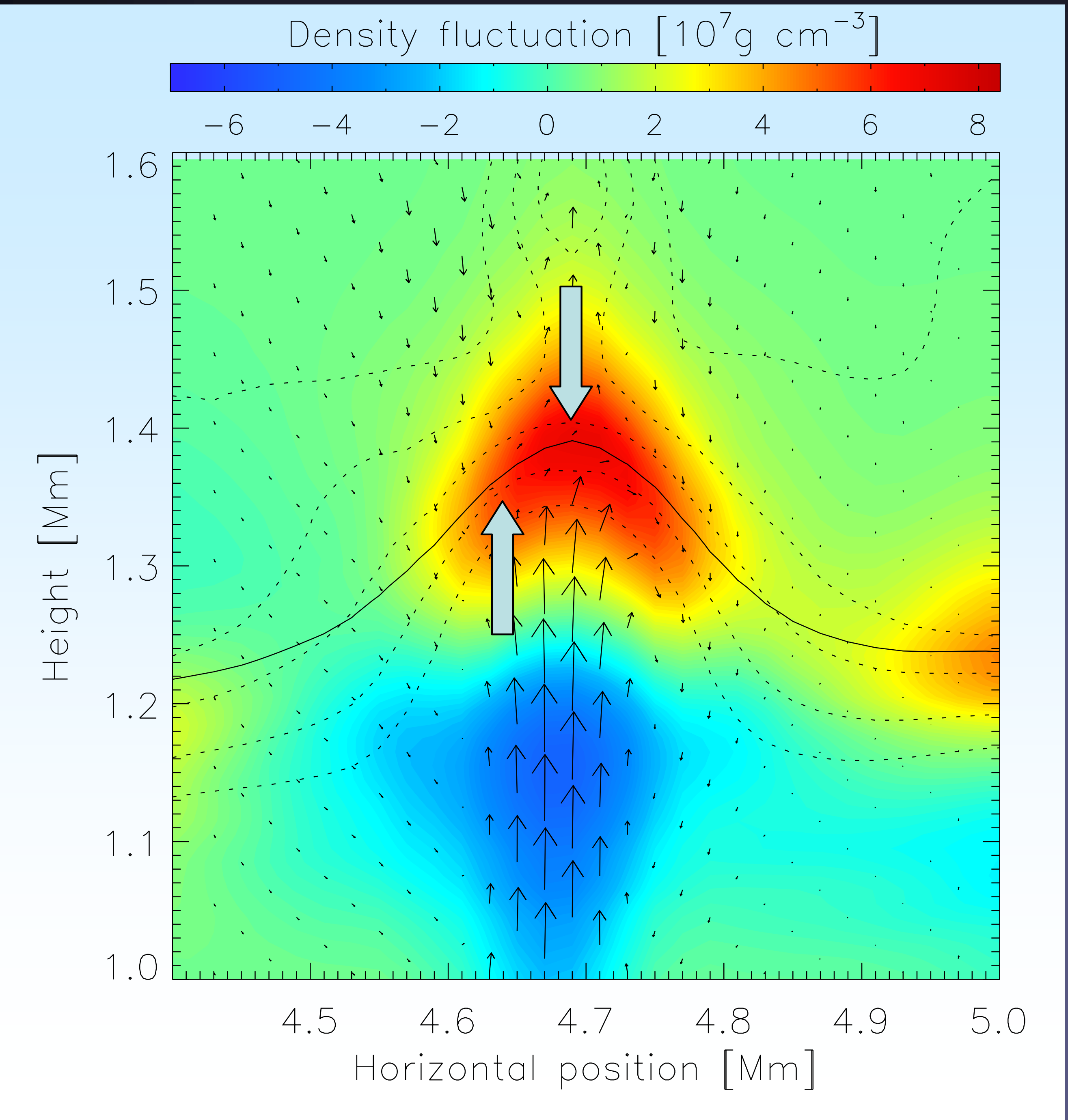
colors: temperature, v_{max} = 3 km/s



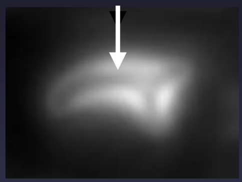
along to the dark lane



Near-surface layers of an upflow plume



cut perpendicular to the dark lane



$\tau_R = 1$

isotherms

„Piling-up" of plasma below the cusp:

→ τ=1 surface elevated

→ central parts cut through lower temperature

→ dark lane appears (≈ 15% contrast)

What next…?

Large scales:

- (small) Sunspots
- extension to chromosphere

Small scales:

- role of the surface dynamo
- penumbral fine structure

Comparison with Solar-B SOT data